International Space Station Robotic Systems and Operations – A Human Factors Perspective

Humans in the Loop

Planning

Seeing

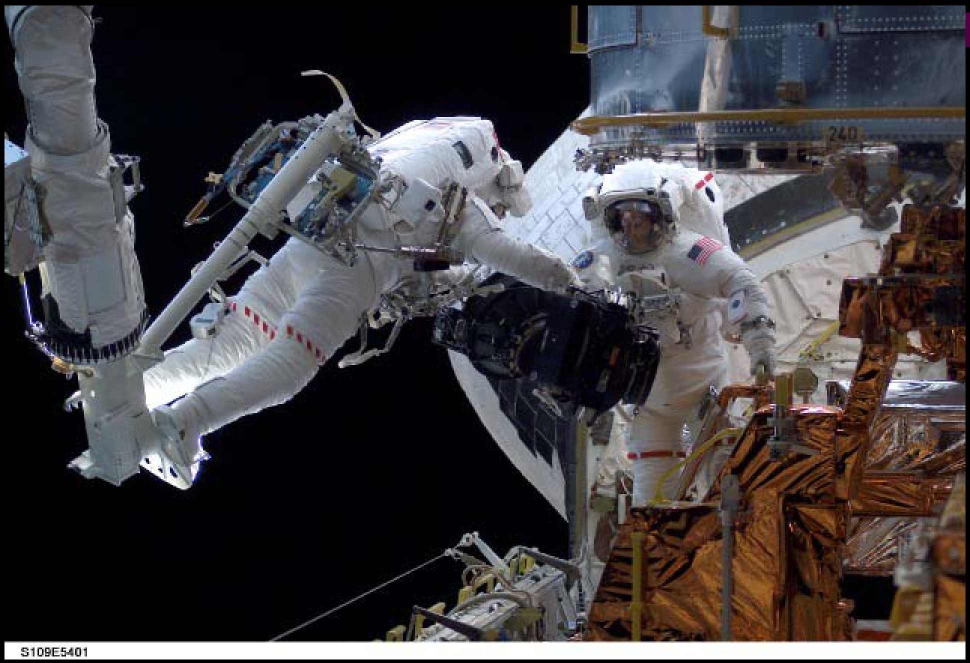
Communicating

Performing

Managing

Deciding

Adjusting



Controlling

Translating

Reaching

Remembering

Behaving

Perching

Human Factors Considerations in the Design of ISS Robotic Systems and Operations

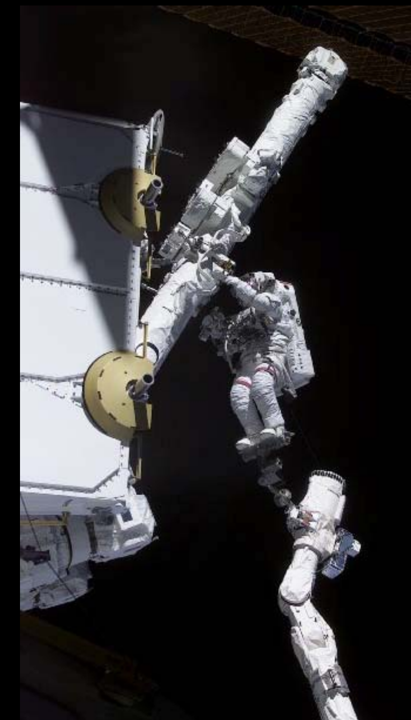
- Robotic workstation topography and design
- Human-computer interface
- Alignment cues for robotic berthing/mating operations
- Spatial awareness challenges
- Integration of supplemental displays to enhance operator global situational awareness
- Preservation of critical skills during long-duration missions

International Space Station Robotic Systems

When fully assembled the International Space Station will have multiple robotic systems

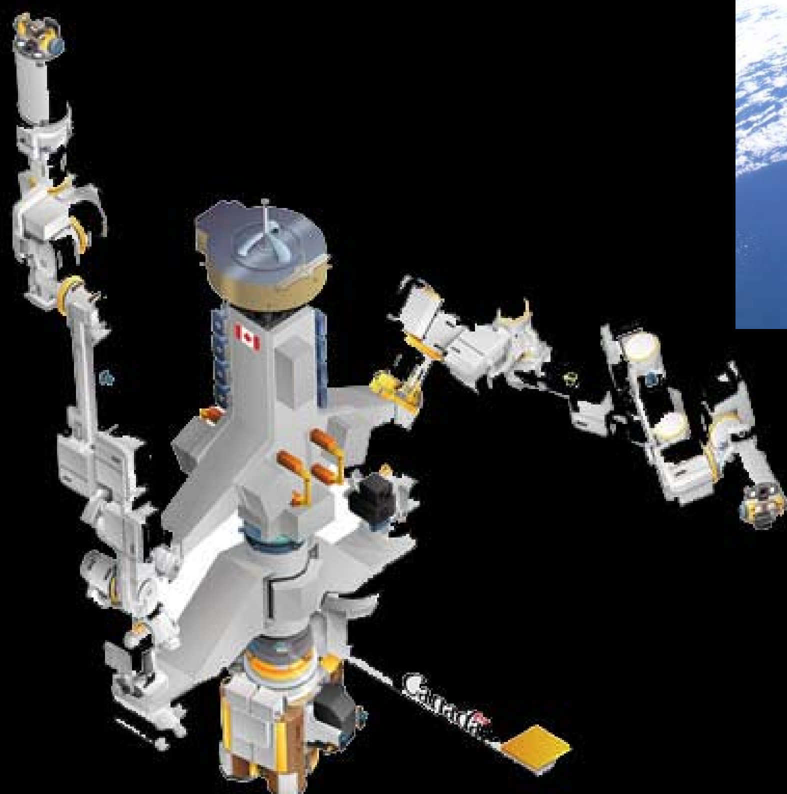
- Five international partners space agencies are involved in the design and manufacturing of these robotic systems
- Mix of 6-DOF and 7-DOF manipulators with unique control systems and algorithms, capabilities, and flying characteristics
- Varying approaches to autonomous versus manual control

Canadian Robotic Systems



Space Station Remote Manipulator System

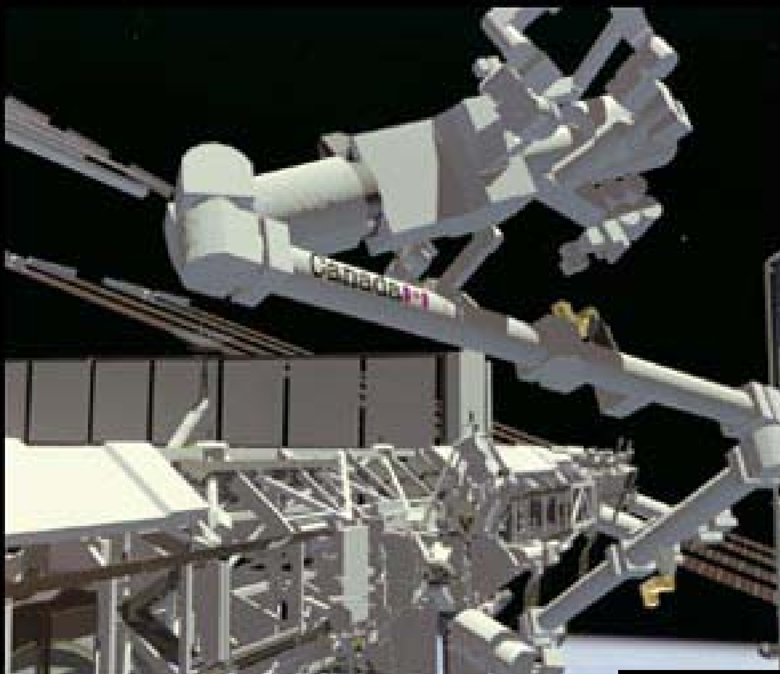
- **7 DOF**
- **2 Latching End Effectors**
- **17 M**
- **Payload Handling < 116,000 kg**



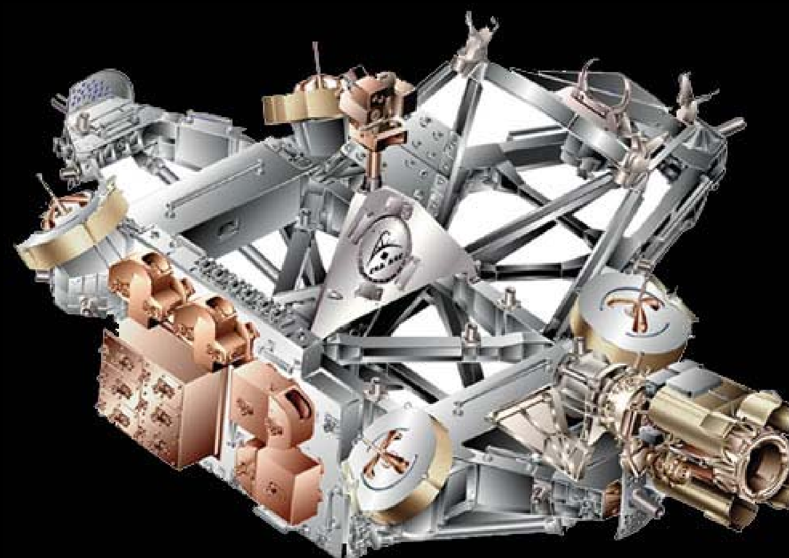
Special Purpose Dexterous Manipulator

- **2 Arms, 7 DOF each**
- **2 Orbital Replacement Unit/Tool Change-out Mechanisms**
- **3.5 M**
- **Payload Handling < 600 kg**

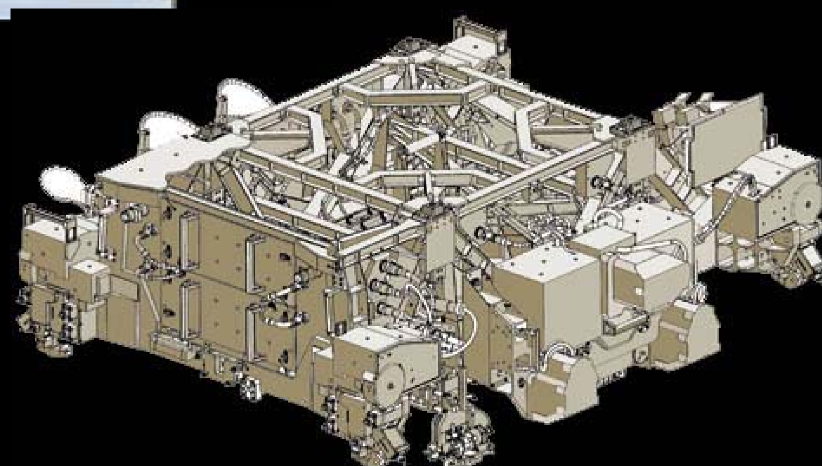
Canadian Robotic Systems



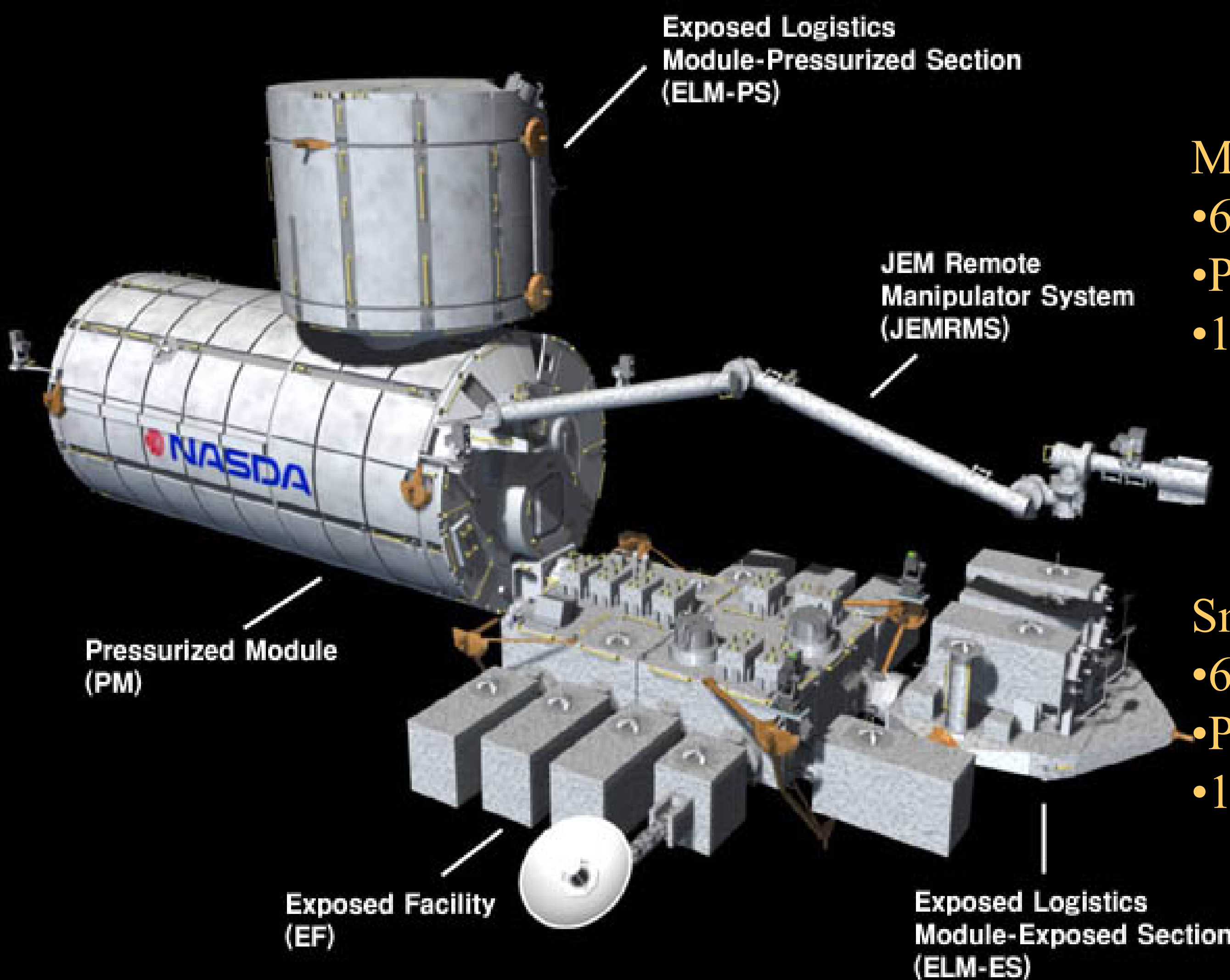
Mobile Base System



Mobile Transporter



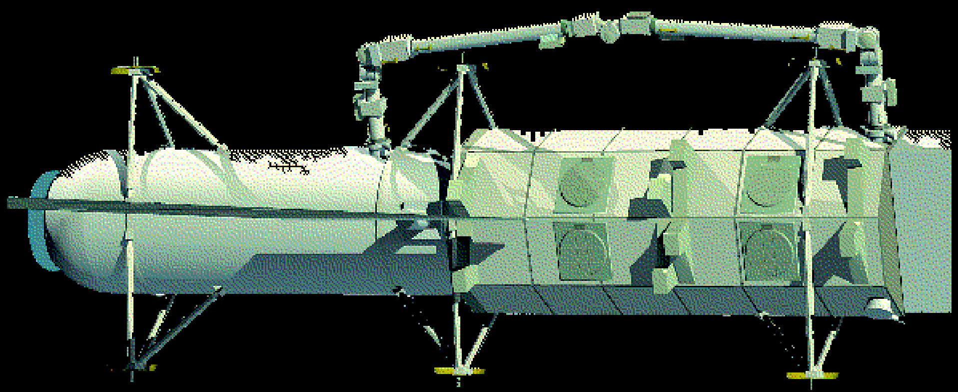
Japanese Robotic Systems

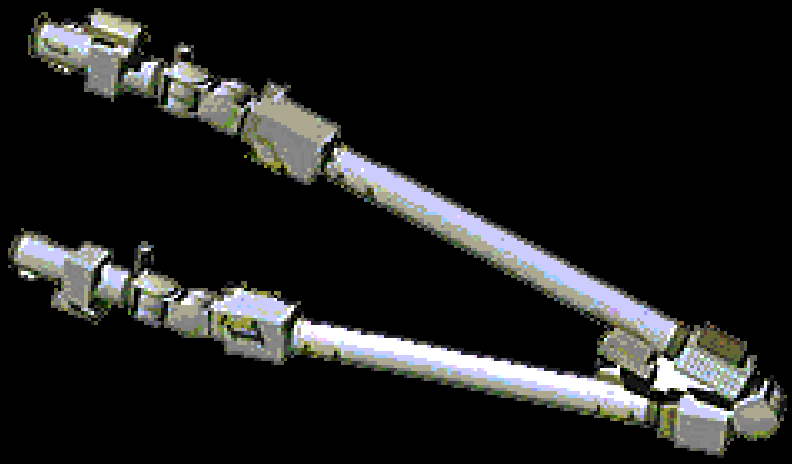


Main Arm
- 6 DOF
- Payload Handling<7000kg
- 10M

Small Fine Arm
- 6 DOF
- Payload Handling<300kg
- 1.7M

European Robotic Arm (ERA)





- 7 DOF
- 11.2 M
- Built by the European Space Agency (ESA) for the Russian Space Agency (RSA) for use on Russian segments
- Attaches only to arm-specific grapple fixtures
- Control either through EVA or IVA interface
- No hand controllers, only auto trajectory sequences and single joint modes

ISS Robotic Systems Design Features affecting human and/or autonomous control

- Trajectory and motion limitations
- Collision avoidance algorithms
- “Smart safing” logic and implementation
- Force moment accommodation
- Integration procedures for autonomous, crew, or ground control

Robotic Control Interface Design Considerations

- Emergency actions, requiring immediate operator action, should be accomplished through hardware switches, not software

- Hand controller design commonality will reduce training, enhance positive habit formation, and reduce the potential for inadvertent or errant commands during manual control

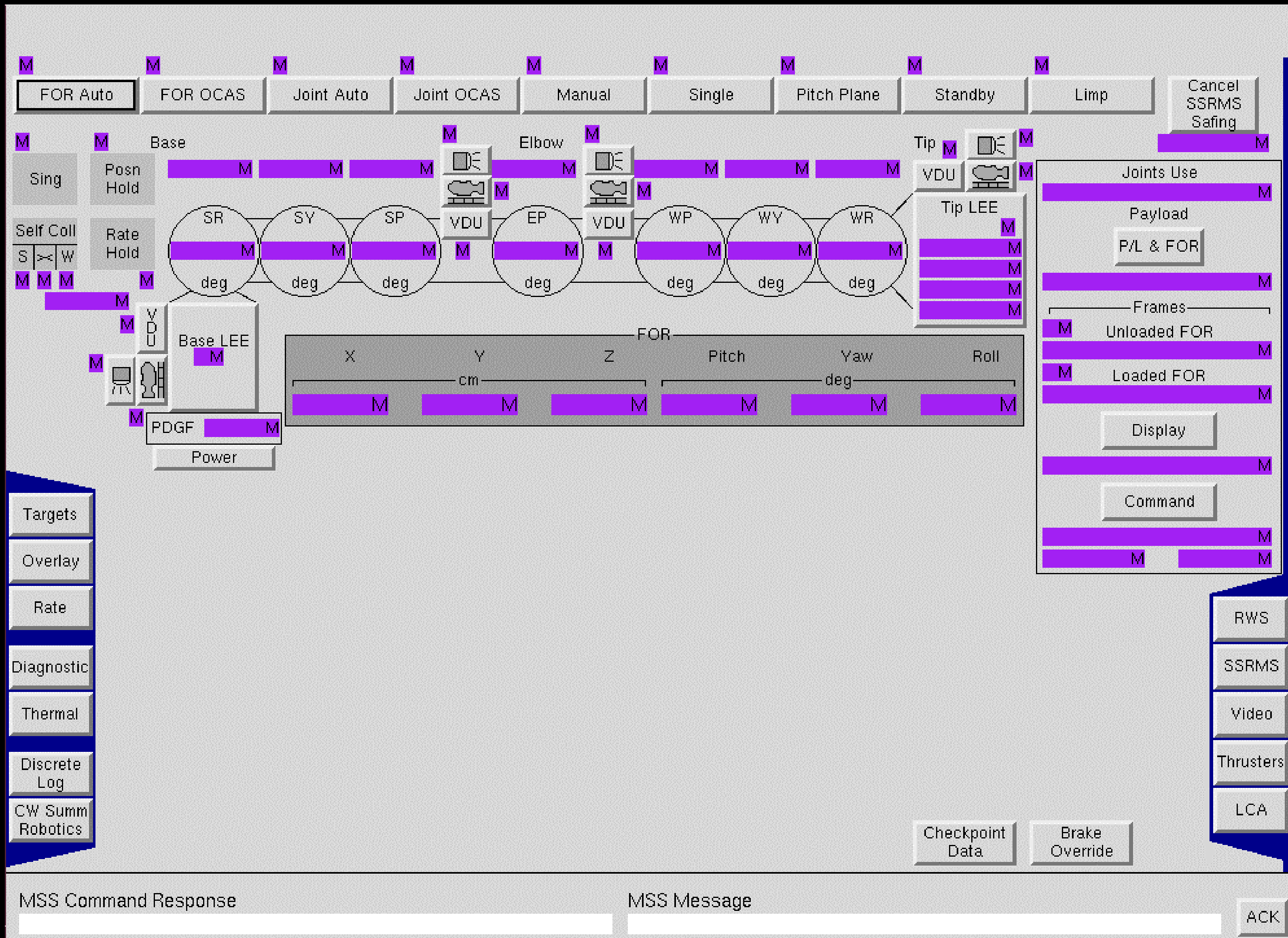
- Design should provide for both single and multi-crew access for manipulator, camera, and support equipment operation

- Postural stability and comfort are essential for extended duration operations (> 7 hours) and for fine motor control in a weightless environment

Robotic Systems Human-Computer Interfaces

- GUIs, icons, and procedures must be readily identifiable and understood by crewmembers from diverse backgrounds and cultures
- commonality within and between systems is crucial
- Procedures must be correlated to the corresponding displays
- ISS Program Display And Graphics Commonality Standard documents graphical features, icons, and color guidelines for developers
    - standardized presentation of manipulator joints & segments position and attitude
    - annunciators only appear when operator's immediate attention required
    - Red = immediate attention to robot to avoid potentially catastrophic event
    - Yellow = out-of-limits condition
    - Orange = robot or hardware in motion or ready for commanded motion

Mobile Servicing System Display

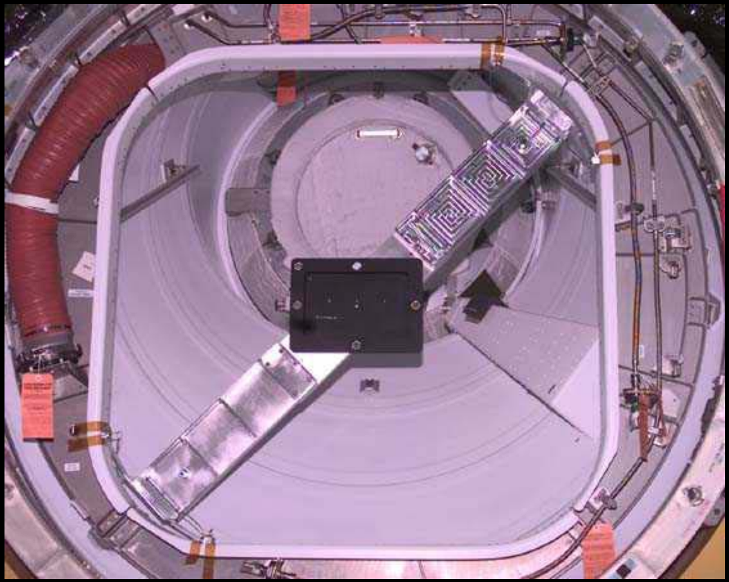


Robotics Alignment Cues

Space Station mechanical systems used for assembly/maintenance operations require precise alignment of the elements

- Suite of mechanical systems - element-to-element, element to truss structure, truss segments to truss segments
- "Operational" approach and mating corridors
  - Derived from hardware requirements
  - Biased according to the accuracy of cues available
    - camera/target location and mounting precision
    - thermal, vibration, pressure effects
    - overlay alignment & operator parallax/viewing angle
- Fitts law challenges of target characteristics
- Alignment cues affected by extreme lighting conditions
- "Ready-to-latch" status indicators provide distinct cues but are not available with all berthing mechanisms

Cueing Systems for Robotic ISS Assembly Tasks



Spatial Awareness Challenges for Robotic Operations

Understanding and application of coordinate frames essential for manual control tasks and suitable vigilance during autonomous operations

- Operators must integrate and correlate multiple sensors/views

- Few cameras on ISS exterior; direct views rarely, if ever, available. If manipulator-based cameras are used:
    - point of reference constantly changes during motion
    - field of view insufficient for comprehensive representation of the environment

- Multiple coordinate command and display frames available and selected per operator preference

- Selection of frame of resolution, display frame, and command frame can affect task complexity. Optimum selection determined by:
    - position of manipulator or attached payload WRT base structure
    - vector of arm maneuver
    - available visual cues

Supplemental Displays

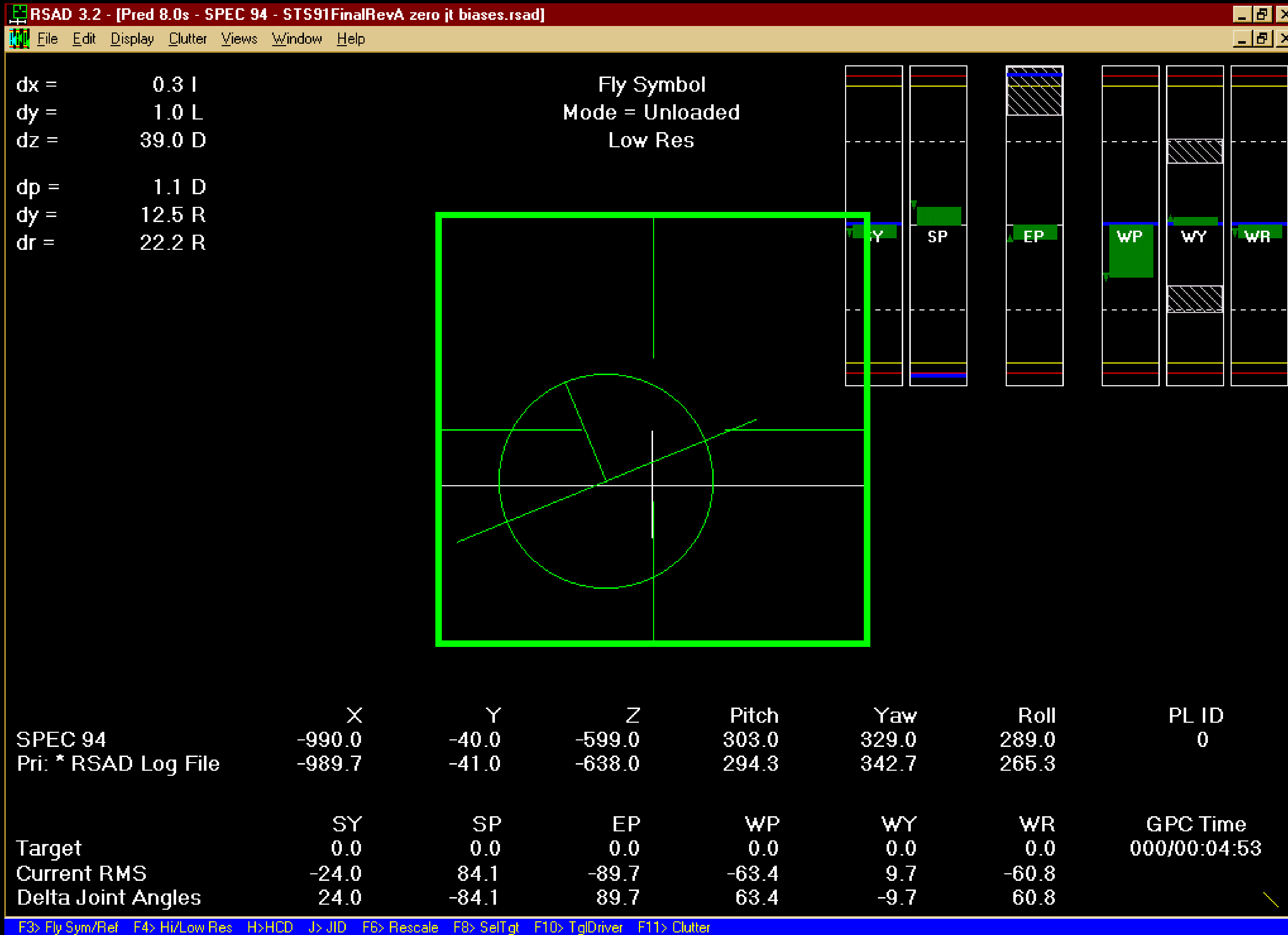
- Operator’s global situational awareness dependent on derived digital information sources and multiple video sources

- Operator’s comprehension of current system status and implications of subsequent control inputs complicated by:
    - Camera field of view limitations
    - Multiple reference frames
    - Dynamic environmental conditions

- Integration of artificial or augmented reality displays, particularly “bird’s eye views” especially useful to enhance operator’s situational awareness

- Supplemental displays can potentially increase complexity of operator’s mental model of the progress of the manipulator or system

Robotics Situational Awareness Tools



Robotics Bird's Eye View Display

Preservation of Robotic Skills During Long-Duration Missions

ISS Expedition crews will perform complex robotics tasks and procedures during extended duration missions

- Allocation of functions among long duration ISS crewmembers, visiting Space Shuttle crewmembers, and ground control is an evolving process
  - Visiting Space Shuttle crewmembers excellent resources for "late development" tasks
  - Recent concept is for Mission Control to act as backup operator/safety observer

- on-orbit training necessary to maintain the high level of proficiency required for complex robotic tasks

- real-time on-orbit "operations-specific" training
  - video-teleconferences conducted with Mission Control to provide discussion of task and procedure modifications
  - uplink or transfer of training videos and computer

- <u>Design of systems for future long duration space missions should include provisions for operating actual system in a simulation mode</u>

Onboard and Remote Site Training Devices

Stowage concerns for ISS long duration missions dictate that system be as compact as possible

-current configuration uses multiple computer platforms

System must run on the existing computer platforms available on the ISS and must be able to interface with, or simulate, the video system

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